The Modification of Wind Turbine Performance by Statistically-Distinct Atmospheric Regimes

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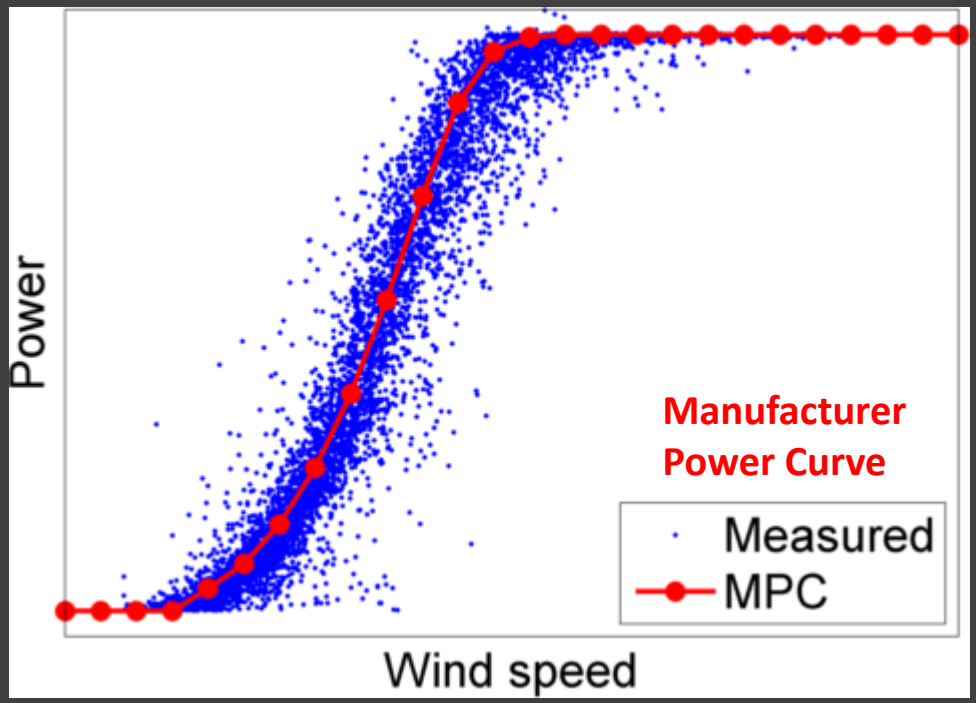
AMS Presentation 24/01/12

Under Review in Wind Energy

Wind Turbine Power Curve Relates Wind Speed at Hub to Power Output

Courtesy of Matt Aitken



Why can the observed data deviate from the manufacturer's predicted output?

Deviations Can Be Created by Atmospheric Forcings

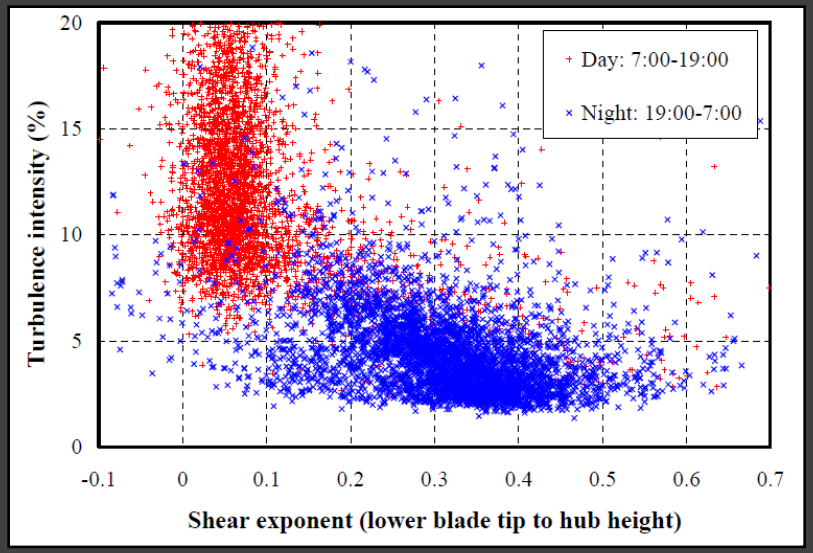
Turbine power production influenced by related factors:

- wind shear across the rotor
- boundary layer turbulence
- stability

  - Elliot & Cadogan 1990
  - Hunter et al. 2001
  - Sumner and Masson 2006
  - Van den Berg 2008
  - Antoniou et al. 2009
  - Wagner et al. 2009
  - Wharton & Lundquist 2012

Day -> Convective, Turbulent, Low Shear

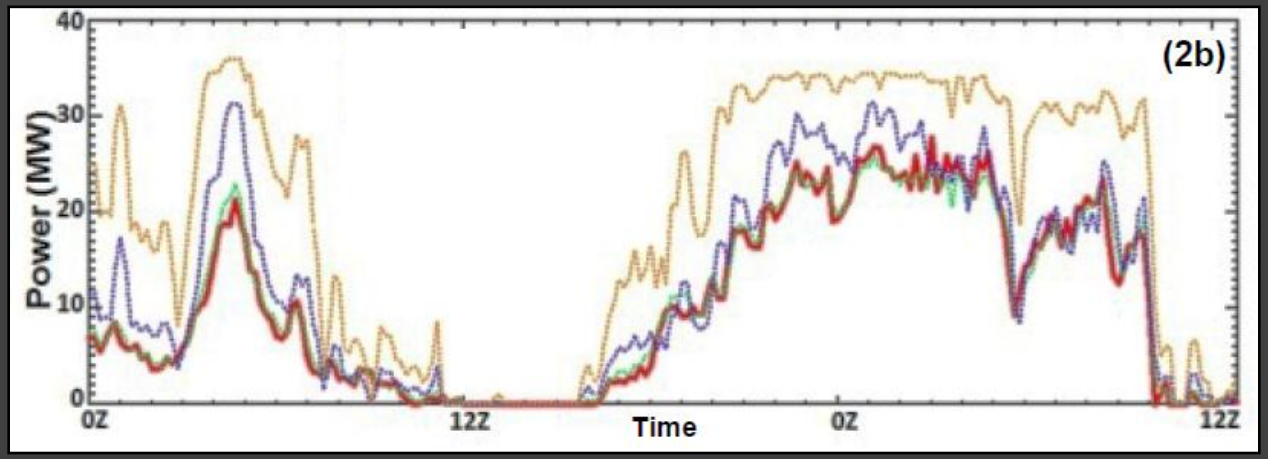
Night -> Stable, Non-Turbulent, High Shear



Rareshide et al. 2009

Can Nacelle Wind Data Capture Atmospheric Dependencies?

- Many farms are data sparse with at most one 60m met tower
- But modern turbines typically span 40-120m!

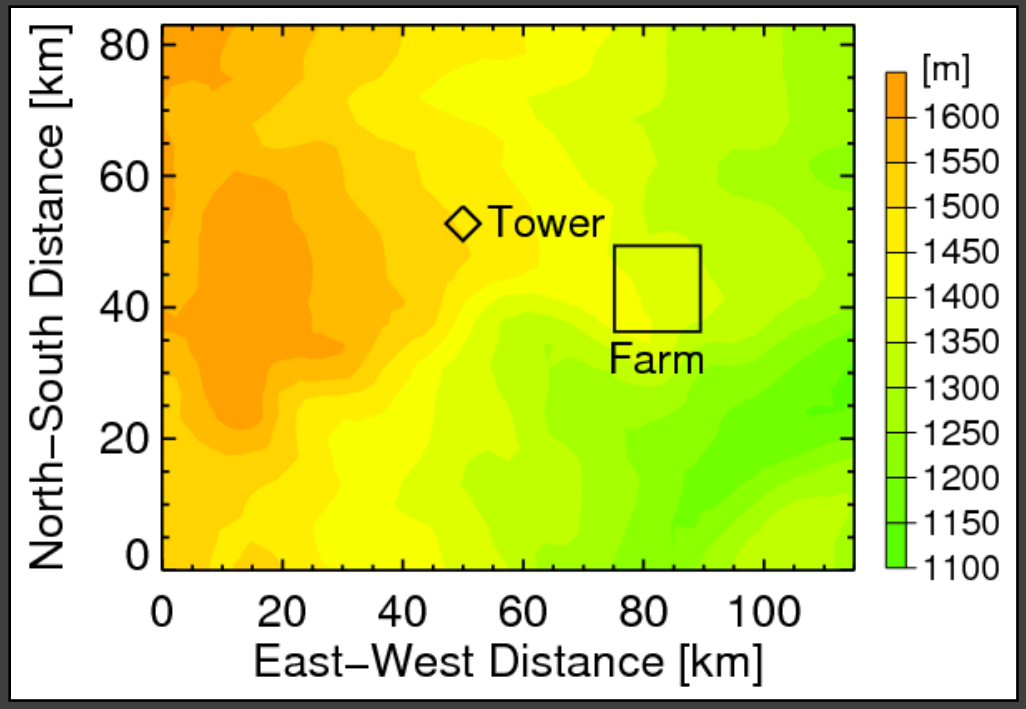


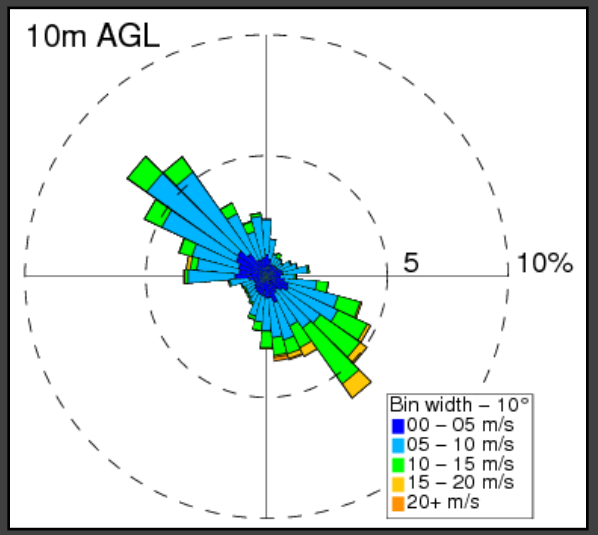
Met Tower 1
Met Tower 2
Averaged Nacelle
Substation

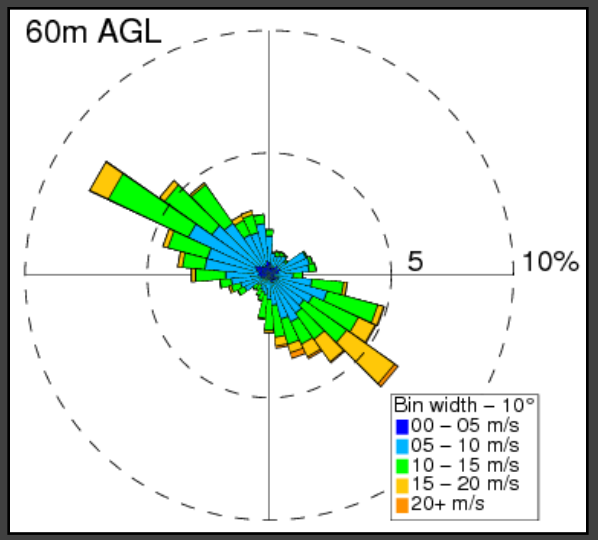
Kankiewicz, Li, Finley 2010

We Use Nacelle Winds From Central North American Plains Wind Farm

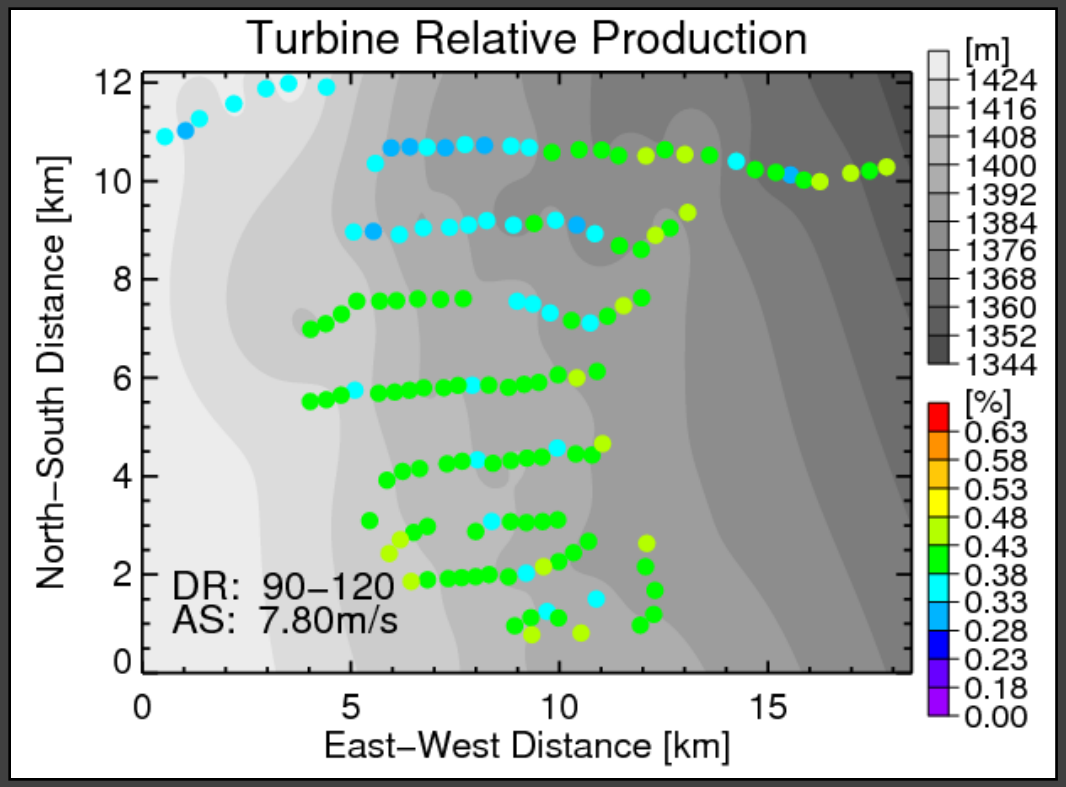
- 134 1.5MW Turbines
- 60m meteorological tower
- Spring data used (Apr-May)
- Strong diurnal cycle in U, T







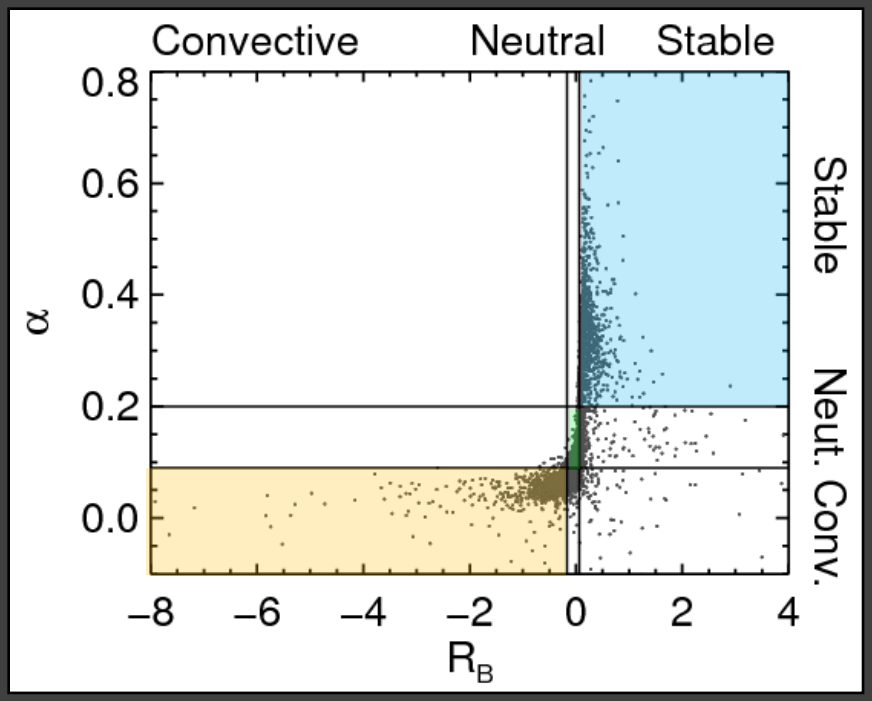
Spatial Analysis of Farm Production Illustrates Possible Wake Effects

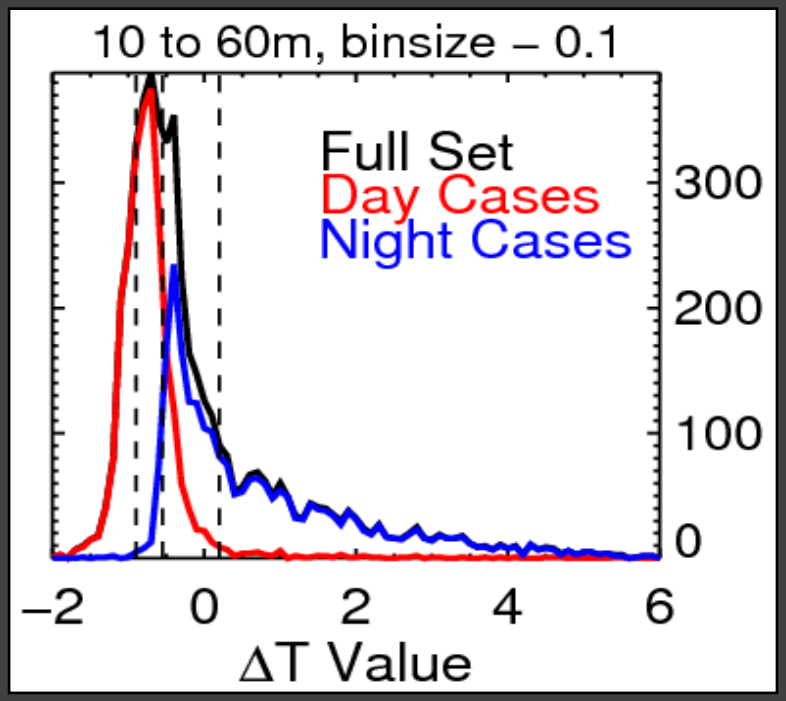


Potentially waked turbines were flagged according to IEC 61400-12-1

- Wind sectors removed based on distance to obstruction
- < 20D ≈ 1600m

Binning Metrics Included Stability, Bulk Layer Differences in Temperature



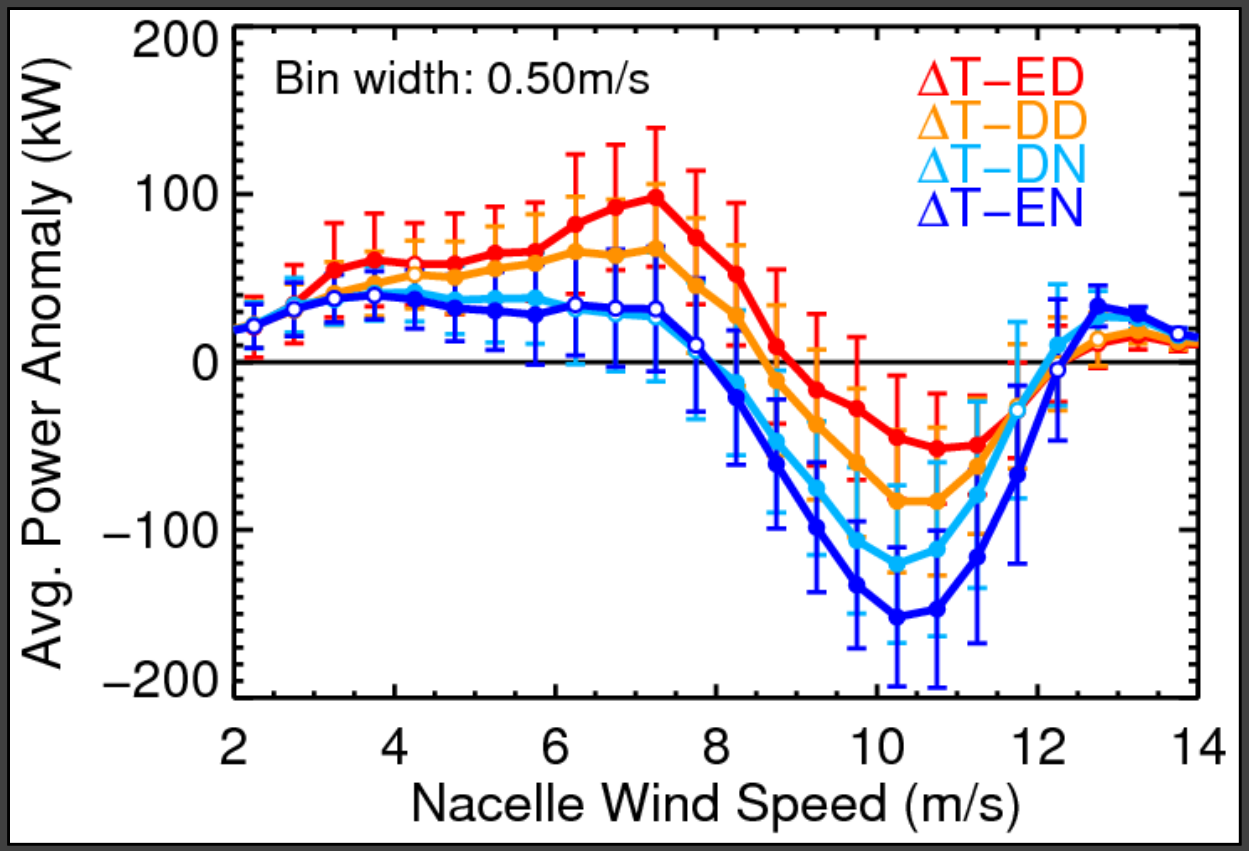


$$U_2 = U_1 \left(\frac{z_2}{z_1}\right)^{\alpha} \qquad R_B = \frac{g \cdot \Delta\theta_V \cdot \Delta z}{\overline{\theta_V} \cdot \left(\Delta u^2 + \Delta v^2\right)}$$

ΔT regimes:

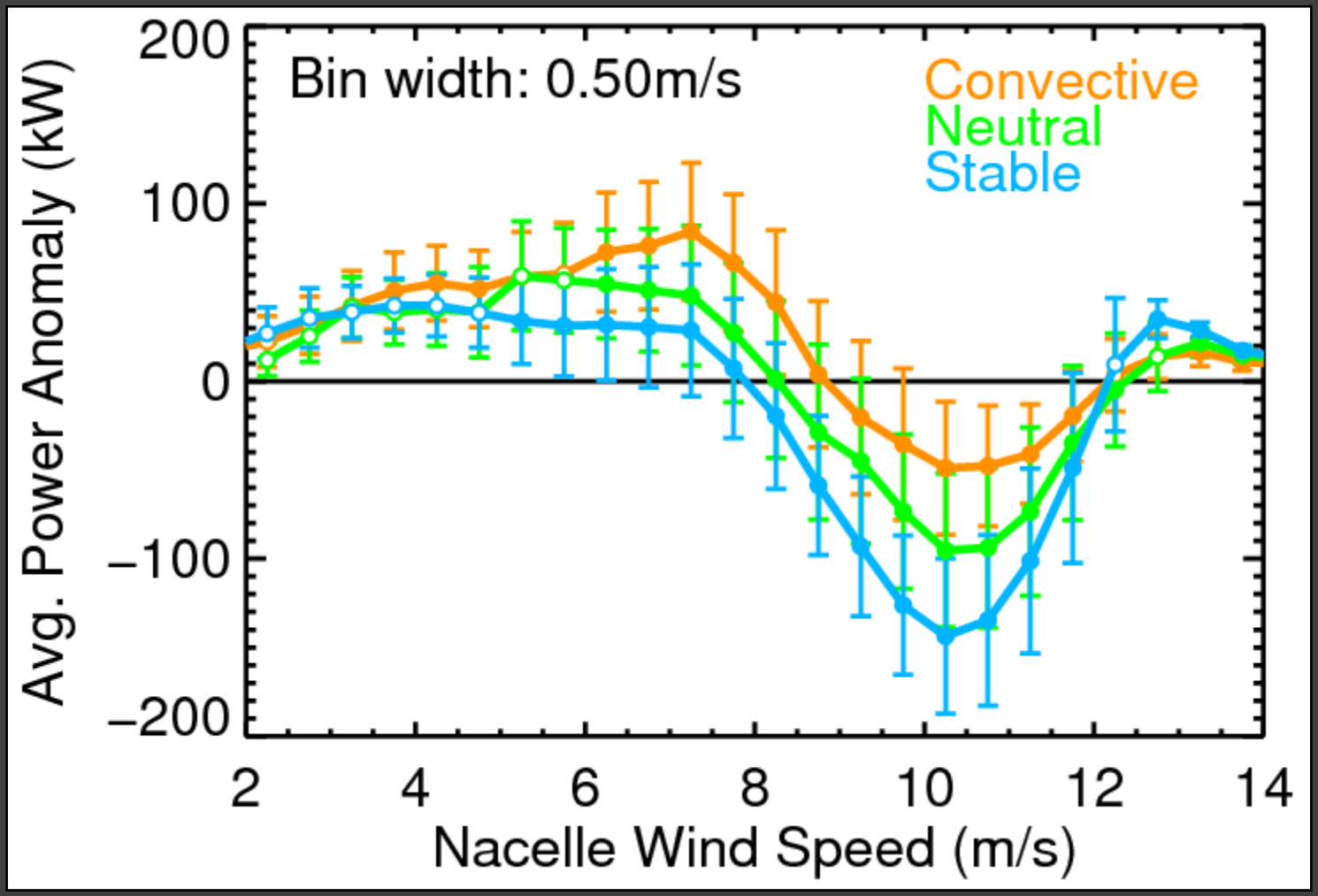
- Day exclusive (<-1)
- Day dominant (-1 to -0.55)
- Night dominant (-0.55 to 1)
- Night exclusive (>1)

Bulk Layer Differences in Temperature Yield Largest Curve Separation (107kW)



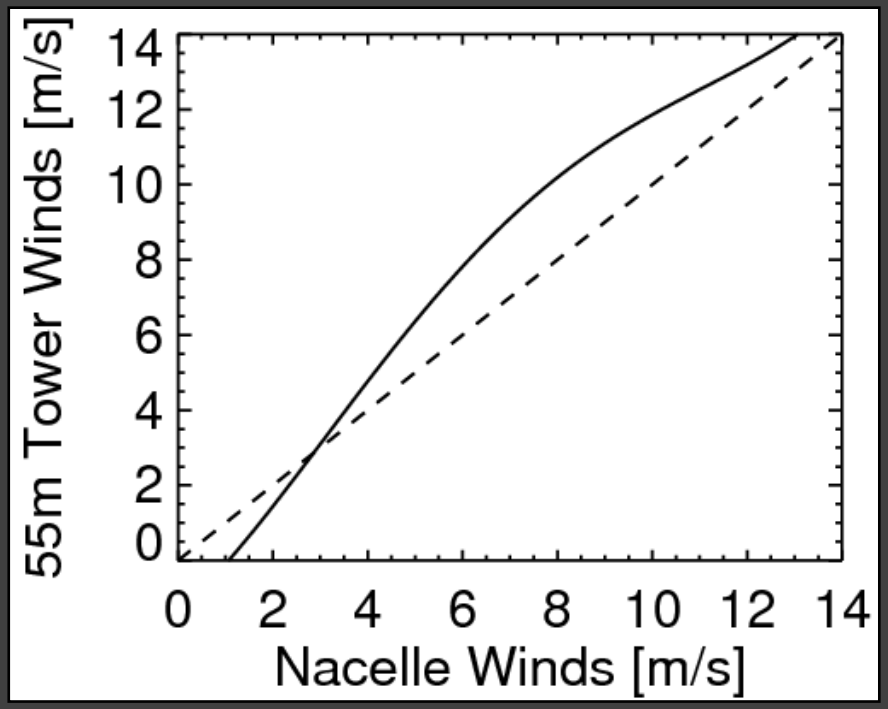
Open circles indicate **not** statistically significant according to rank-sum test

Results are Similar Using Stability Metric; More Universally Applicable?



Monte Carlo Testing Shows Nacelle Wind Differences to be Significant

Adapted from Antoniou and Pedersen 1997



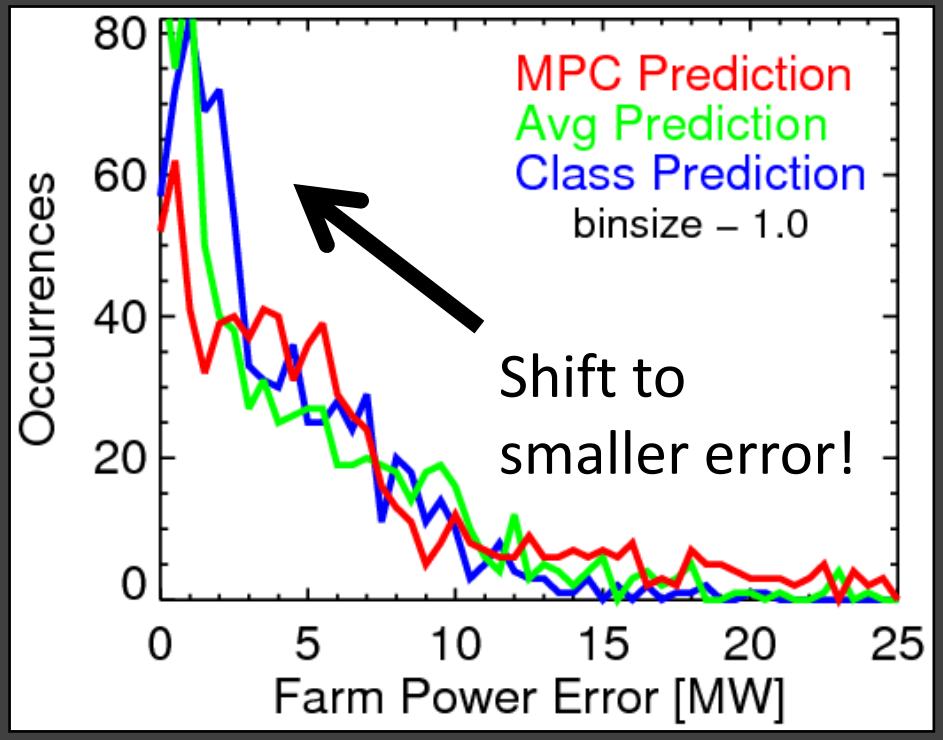
Assumed Systematic Bias

1000 run Monte Carlo test at **10.25m/s** bin using rank-sum test, **1m/s random error**

- **100%** significant at **0.01** level
- Avg. max power difference = **58kW**

Simplistic Forecasting Application Demonstrates Potential Benefit

April-May data and correlations used to predict June farm power production – improved results!



Conclusions

- Atmospheric binning of wind farm power data is possible with nacelle wind data
- ΔT differences are effective at binning data when the diurnal cycle is strong
- Improved power prediction is possible using condition based power curves

Thank You!

Any questions?